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Abstract

This research investigates the impact of time pressure and individual differences on performance and learning in a Real-Time Dynamic Decision Making (RTDDM) task. Our results indicate that individuals with high spatial WM capacity improved their performance in a high time pressure environment, while individuals with low spatial WM capacity did not. Our results also indicate that individuals with high linguistic WM capacity performed worse than individuals with low linguistic WM capacity. These results suggest that in high time pressure tasks, spatial thinking helps decision makers to build more efficient and effective cognitive models of the environment. We conclude by discussing the implications of these results for training and for the design of computer support in RTDDM tasks.

Introduction

Real-Time Dynamic Decision Making (RTDDM) tasks have three main characteristics: a) the decision maker has to make a series of interdependent decisions; b) the environment changes because of exogenous events and because of prior decisions; and c) the pacing of decisions is dictated by the task rather than by the decision maker (Brehmer, 1990). This research investigates the impact of time pressure on performance and learning in a RTDDM task. It also studies the impact of linguistic and spatial Working Memory (WM) capacity on performance and learning.

Theory

WM is the system for *holding* and *manipulating* information during the performance of cognitive tasks (Baddeley, 1990). Limitations in WM capacity have been recognized as a major bottleneck in human cognitive processing. We would expect that differences in WM capacity will have a great impact on how individuals perform and learn in RTDDM tasks because these environments impose high cognitive workloads. More specifically, we would expect that individuals with high WM resources should be better able to cope with rapidly changing environments. Also, since WM is used for both performance and learning, we would expect that decision makers would learn better decision strategies when they are *first* trained in a low time pressure environment, and then they are asked to make decisions in a higher time pressure environment. Conversely, individuals that are trained from the beginning in a high time pressure environment should find it harder to learn better decision strategies because all their cognitive resources are devoted to executing the task, and they have less spare resources devoted to learning. This prediction should be mediated by individual differences in WM capacity.

WM is divided into two subsystem: 1) a linguistic sub-system, and 2) a spatial sub-system. In the linguistic sub-system, information is kept in linguistic code, and the processing of this information can be characterized as sequential and propositional. In the spatial sub-system, information is kept in visual code, and the processing can be characterized as more parallel and analogical. There is a strong evidence that language processing and spatial thinking are supported by separate pools of WM capacity (Shah and Miyake, 1996).

Prior studies have shown that individuals with high linguistic WM capacity perform better than individuals with low linguistic WM capacity in a variety of real-time tasks such as reading comprehension (Just and Carpenter, 1992) and phone-based interaction (Huguenard, Lerch, Junker, Patz and Kass, 1977). Therefore, we would expect that individuals with high linguistic WM capacity will perform and learn better than individuals with low WM capacity in a RTDDM task.

We did not make any predictions about the impact of individual differences in spatial WM capacity since our task is embedded in a scheduling decision making environment that requires the processing of numbers. Number processing is mainly handled by the linguistic sub-system in WM (Shah and Miyake, 1996). But it is possible that decision makers with high spatial WM capacity may decide to build a spatial model of the task, and use this model to make decisions. Since spatial thinking exhibits more parallel processing than linguistic processing, individuals with high spatial WM capacity may be better able to handle the high cognitive demands of RTDDM tasks if they can build a visual model of the task.

Laboratory Study

We used a simulation tool that reproduces the scheduling of mail in the sorting factories of the United States Postal Service (USPS, Lerch, Ballou and Harter, 1997 for a detailed description of the simulation). The task requires the scheduling of mail sorting jobs into a limited number of sorting machines. Performance was measured by the number of pieces of mail (trays of mail) that are not sorted in time to meet their deadlines. Therefore, the more trays of mail that are missed, the worse the performance of the decision maker.

We ran 25 participants using this simulation. Each participant was run in five consecutive days, and paid $50 at the end of the 5 days. In the first two days, each participant completed three psychological tests: the Reading Span Test (Daneman and Carpenter, 1980) that measures WM capacity for language processing; the Spatial Span Test (Shah and Miyake, 1996) that measures WM capacity for spatial thinking; and the Raven Progressive Matrices Test (Raven, 1962) that measures general analytical intelligence. We decided to use the Raven test because there is a strong correlation between measures of WM capacity and general intelligence (Kyllonen and Christal, 1990). We wanted to make sure we isolated the impact of WM capacity, without confounding these results with the impact of general intelligence on performance and learning.

In the last three days, each participant was randomly assigned to one of two groups: the Fast-Fast condition and the Slow-Fast condition. The simulation was run either in a Fast mode (8 minute trials), or in a Slow mode (16 minute trials). In the Fast-Fast condition, participants ran the simulation 6 times for three days in the Fast mode (18 trials over three days). In the Slow-Fast condition, participants ran the simulation in the Slow mode for the first *two* days. In these *two* days, they only ran 3 trials per day, so their total time on task was the same as the time on task for Fast-Fast participants (Slow-Fast: 3 trials x 16 minutes = 48 minutes per day; Fast-Fast: 6 trials x 8 minutes = 48 minutes per day). In the third (last) day, the Slow-Fast participants ran the simulation 6 times in the Fast mode (8 minute trials), the same as the Fast-Fast participants. We expected Slow-Fast participants would exhibit more learning than Fast-Fast participants.

Results

Figure 1 shows the results for the two experimental groups. We averaged the results of each participant across trials for each day so each participant had only three repeated performance measures (one for each day).

We ran an analysis of variance with three repeated measures using the measures of individual differences as co-variates. We also ran the same analysis using the raw performance data for each trial (18 trials for Fast-Fast and 12 trials for Slow-Fast). Since the statistical results are the same, we only report results using average performance per day.

There is no significant difference between the two experimental groups [$F(1,20)=.004$, ns], and no significant interaction between group and day [$F(2,40)=1.36$, ns].

Figure 2 shows the results when we divided the participants into two groups (low and high) using the mean of the linguistic WM capacity test (Mean linguistic WM=61.0; 14 subjects were classified as low and 11 subjects as high). High linguistic WM capacity individuals performed *worse* than individuals with low linguistic WM capacity [$F(1,20)=6.903$, $p<.02$]. This result is in the opposite direction from our prediction. There is no significant interaction effect between linguistic WM and day [F(2,40 =.141, ns].

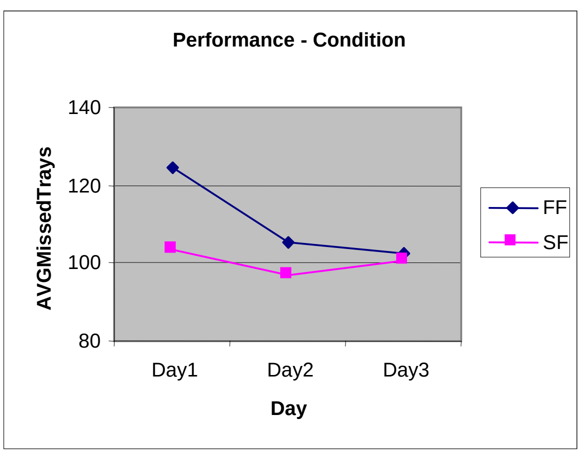

Figure 1. Performance for FF and SF Conditions

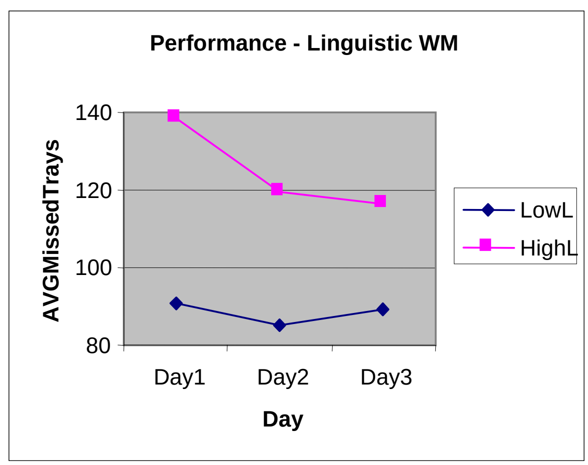

Figure 2. Performance for Low and High Linguistic WM

Figure 3 shows the results for the high and low spatial WM capacity groups. There is no main effect between the two groups ($F(1,20)=.014$, ns), *but* there is a significant interaction effect between spatial WM and day [$F(2,40)=3.758$, $p<.04$] (Mean Spatial WM=42.0; 13 subjects were low, and 12 subjects were high). The high spatial WM participants were able to improve their performance across the three days while the low spatial WM capacity participants did not. It is especially interesting to notice that the interaction effect is especially strong in the last day. In this day, some of the participants (in the Slow-Fast condition) experienced the simulation with the high time pressure environment (Fast mode) for the first time. The results indicate that in both conditions, participants with high spatial ability, after few trials, are able to cope with the high time pressure environment better than individuals with a low spatial WM capacity.

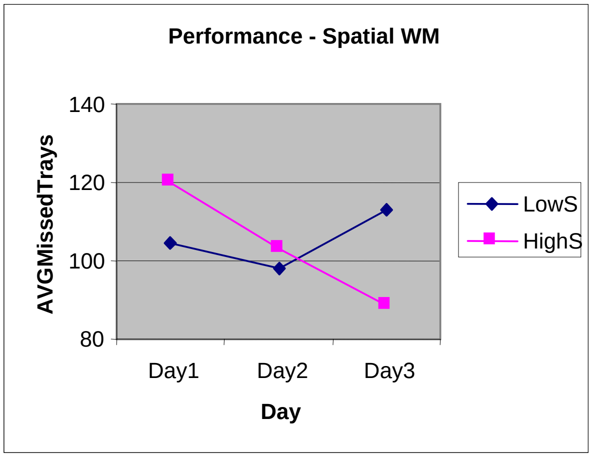

Figure 3. Performance for Low and High Spatial WM

There were no significant differences for the Raven test. There is no main effect between low and high Raven participants [$F(1,20)=2.151$, ns], and there is no significant interaction effect between Raven and day [$F(2,40)=.283$, ns].

Discussion

Our time pressure manipulation did not work. Participants in the Slow-Fast condition did not learn better than participants in the Fast-Fast condition. One possible explanation is that the Slow mode is still too fast to support learning. We are currently running a Very-Slow-Fast condition (two 24 minute trials for the first two days, and six 8 minute trials for the third day). The results suggest that training people in a very low time pressure condition may have a positive impact on performance in the high time pressure environment.

The results for the linguistic WM test were unexpected. Individuals with low linguistic WM capacity *outperformed* individuals with high linguistic WM capacity. We need to investigate how these two groups are processing information in order to explain these results. We have conducted thinking-aloud protocols with low and high linguistic participants. The analysis of the verbal protocols suggest that high linguistic WM capacity decision makers spend too much time pondering about making the right decision, while low linguistic WM capacity decision makers just do it. It is possible that in high time pressure environments, a higher capacity for exploring large problem spaces in a sequential manner (high capacity in the linguistic sub-system) may not provide any advantage, but rather it may deteriorate performance.

Finally, individuals with high spatial WM capacity exhibited learning, while low spatial WM participants did not. This is after controlling for differences in analytical intelligence as measured by the Raven test. If high spatial WM individuals are capable of improving their performance in these environments, perhaps all individuals can be helped by training them with aids that facilitate and support visual processing. In high time pressure tasks, the ability of processing information more efficiently is of the essence. Computer-based tools for aiding RTDDM should be more visual and spatial, instead of just providing more information. Although more research is needed to better understand the role of spatial thinking in a range of RTDDM tasks, our results suggest that visualization tools for training and aiding decision makers in high time pressure tasks may be the way to go.

Acknowledgements

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References

Baddeley A. D. (1990). *Working Memory: Theory and Practice.* Boston: Allyn and Bacon.

Brehmer, B. (1990). Strategies in Real-Time, Dynamic Decision Making. In R.M. Hogarth (Ed.), *Insights in Decision Making,* University of Chicago Press, 262-279.

Daneman M. and P.A. Carpenter (1980). Individual Differences in Working memory and Reading. *Journal of Verbal learning and Verbal Behavior, 19,* 450-466.

Huguenard, B.R., Lerch, F.J., Junker, B.W., Patz, R.J. and Kass, R.E. (1997). Working Memory Failure in Phone-Based Interaction. *ACM Transactions on Computer Human Interaction,* 4, 67-102.

Just, M.A. and Carpenter, P.A. (1992). A Capacity Theory of Comprehension: Individual Differences in Working Memory. *Psychological Review,* 99, 122-149.

Kyllonen, P.C. and Christal, R.E. (1990). Reasoning Ability Is (Little More Than) Working Memory Capacity? *Intelligence,* 14, 389-433.

Lerch, F.J., Ballou, D.J. and Harter, D.E. (1997). Using Simulation Based Experiments for Software Requirements Engineering. *Annals of Software Engineering,* 3, 345-366.

Raven J.C. Advanced Progressive Matrices test. (1962) (distributed in the US by the Psychological Corporation).

Shah P. and Miyake A. (1996). The Separability of Working Memory Resources for Spatial Thinking and Language Processing: An Individual Differences Approach. *Journal of Experimental Psychology,* 125, 4-27.